An Automatic Direction Control System for Shield Tunneling

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Abstract

We have developed the system operated by means of a computer for controlling direction of shield machine, which is one of the important parts in controlling shield method.

The system consists of three sub-systems. The automatic survey system measures the position and direction of shield machine. The data acquisition system measures the operational data of shield machine. The shield jack control system controls the direction of shield machine.

An artificial intelligence is used for judging a control of direction, and according to inference and intelligent base, the judgement of an engineer is replaced with a computer.

1. Introduction

The shield driving method is widely used at present for tunneling subways, water supply and drains in cities. Recently, mechanical shield machines have entered the mainstream of shield driving methods, and increases in working speed and man-hour savings, as well as improved safety are planned. Accompanied by such conditions, more complicated and divergent controls over excavation are required, because the cutting face cannot be observed visually and various machine are working.

However, excavation control depends much on the experience of engineers and a standardized control method is not yet to be established. Therefore, problems caused by meandering routes, ground subsidence, and machine failures are apt to occur.

To prevent such problems, and to establish a more accurate method of drive control, apart from conventional excavation control based on experience and intuition, development of automation technology for shield working, based on real-time data analysis, are proceeding.

This paper outlines the directional control system of a shield machine, which is an element of automated shield driving work, and details the control method employing a logical language Prolog.

2. Construction of Direction Control System

2.1 Overall constitution

This system consists of the following three systems:

[1] Automatic survey system which measures the position and direction of the shield machine.

[2] Driving data acquisition system which monitors and records the behavior of shield machine driving.

[3] A shield jack control system which controls the direction of the shield machine along the planned route.

The overall constitution of the system is shown in Fig. 1, and the functions of the respective systems are described in the following:

1) Automatic Survey System

The automatic survey system consists of a target to be installed in the shield machine, detection instruments installed in the rear segment (electronic total station with built-in TV-camera) and measurement calculation equipment (image processing device and personal computer) installed in a surface monitoring room. The system continuously measures the position and direction of the shield machine from the value of the image processed target picture, and the distance and angle measurements by the electronic total station.

2) Driving Data Acquisition System

The driving data acquisition system consists of sensors and data collection equipment installed on the shield machine, and an Engineering work station (EWS) (commonly used with a shield jack control system) to be installed in the monitoring room, and measures and records operating information.

3) Shield Jack Control System

The shield jack control system consists of EWS installed in the monitoring room, terminal equipment for control (personal computer and relay box installed on the shield machine.) Data on position and direction of the shield machine from the automatic survey system, and data on directional control from the driving data acquisition system are analyzed, and the system automatically controls the shield jack so that the shield machine is driven along the planned route.

2.2 Outline of Control System

The directional control method of this system is basically the same as the method used so far, to select shield jack of the shield machine and operate it, to give a moment to the shield machine to change its driving direction.

This control system has a computer to select a driving jack to give a moment to the shield machine, using an AI method such as pattern matching or inference, rather than skilled engineers.

The driving jack is selected through a comparison and study of data on shield machine position and direction obtained with a survey system and a data acquisition system, data of past driving locus, and knowledge and experience of skilled engineers.

Then, a certain section is driven with the selected driving jack, to determine the correctness of the control results. The next driving jack is selected in consideration of the newly acquired information. The new information obtained is automatically stored in the database.

Differing from conventional methods, it has the ability to control without using a formula model, and this method can take in elements that are difficult to express numerically, such as experience, knowledge, and intuition as the basis of a decision. Therefore, this directional control system can make similar decisions to a skilled engineer. Fig. 2 shows the outline of the direction control system.

3. Directional Control Method

3.1 Basic Structure of Shield Jack Control System

The shield jack control system software, which selects a driving jack and performs directional control in the direction control system, is based on a type of real-time expert system employing the logical language Prolog. The basic structure of the control system software consists of a knowledge base and an inference engine as the core.

The knowledge base contains knowledge related to directional control, and includes a correction amount knowledge base, knowledge base to modify correction amount, and knowledge base for the jack pattern to be used as the bases.

The inference engine is a mechanism for effectively using knowledge for directional control. Fig. 3 shows the basic structure of the software of the shield jack control system.

3.2 Judgement Standard and Amount of Correction of Direction Control

In this system, elements affecting the directional control of the shield machine are classified into the following three, and a knowledge base is constructed.

[1] Locus of driving
[2] Present position of shield machine.
[3] Direction of shield machine.

1) Basic Pattern and Locus Pattern

Select the discrepancy of direction in the up/down left/right directions within the two positions (for instance, amount of discrepancy from the planned route at the starting point and end point for driving one ring) of an arbitrary range of the planned route, obtained in the survey system. The line segment connecting these two points indicates outline of the shield machine's motion between these points, and its relative location to the planned route can be classified into eight categories as shown in Fig. 4. They are called the basic patterns.

In this system, it is decided to use a combination of three patterns from these basic patterns, which is called a locus pattern. This locus pattern is the standard for monitoring the behavior of the shield machine. Fig. 4 shows an example of a locus pattern.

2) Present Position of the Shield Machine

When approaching the shield machine, which has deviated from the planned route, to the planned route, an abrupt correction over a short distance is not generally desirable for many reasons such as having a bad effect on completed products.

This system, prepares a number of areas with an arbitrary width in which the weight of the value is assigned to the correction amount in accordance with the discrepancy from the planned route. The number and width of the area are set based on the size of the shield machine or the control limit for the planned route.

3) Direction of Shield Machine

The pitching angle and yawing angle of a shield machine corresponds to the vertical and horizontal movement of the shield machine. A change in the direction of a shield machine generally occurs prior to the generation of a discrepancy from the planned route. This system always follows the shield machine, and measures the direction of the shield machine in accordance with the automatic survey system. Therefore, the future behavior of the shield machine can be anticipated at an early stage.

In this system, therefore, when a change of direction is generated in the shield machine, the change in the direction is added to the correction for directional control, considering that the change of direction will affect the future excavation locus of the shield machine.

3.3 Optimal Correction Pattern and Learning Function

The knowledge base of this system has a learning function to perform optimum directional control in response to changes of geology etc. The learning function renews the knowledge base in accordance with the results of the control, and the concept of "Optimal Correction Pattern" was defined. The optimal correction pattern is an index to judge the effectiveness of control and is set in the knowledge base in accordance with the locus pattern and the present position. Effectiveness is judged from whether the newly obtained basic pattern coincides with the optimal correction pattern, and when they do not coincide, the knowledge base is added or renewed.

Fig. 5 shows a conceptual diagram of an optimal correction pattern. In Fig. 5, past locus pattern is 1-1-7, and the position is included in the area 2, then the optimal correction pattern is 7. If the basic pattern obtained with future excavation is 7, it is judged that the control method is correct, and the present knowledge base is used. If it is not correct, the computer automatically prepares a knowledge base with increased or decreased control amount.

Knowledge in the knowledge base is classified as static mode knowledge and dynamic mode knowledge. The static mode knowledge is a knowledge base in the initial status, and the dynamic mode knowledge judges control effects in accordance with the knowledge base, and the results are automatically generated and added in the knowledge base. The dynamic mode knowledge is added and described in the part of knowledge base which is to be retrieved with first priority within the knowledge base.

3.4 Setting Jack Pattern and Knowledge Base

Various combinations of jack pattern used for directional control can be considered in accordance with the number of jacks installed. However, there are cases in which same or a quite similar rotational moment is generated in spite of the different number of jacks employed. In this system, it is arranged so that a jack pattern with a plural number of jacks is selected. In consideration of operating convenience, the total number of jack patterns are selected to be 20 to 30 types as a base, and these are prepared as jack patterns in the knowledge base. In this knowledge base, jack pattern, correction quantity, correction direction, and standard position where jack patterns will be located are described. Fig. 6 shows an example of a jack pattern knowledge base.

In consideration of practical application, this system is prepared for a shield machine with up to 20 shield jacks, however, if more than 20 shield jacks are used, shield jacks are divided into several groups and are controlled.

3.5 Directional Control Flow

This system receives the calculation results necessary for correcting the direction and the amount of correction, selects corresponding jack pattern from jack pattern knowledge base, sends control signals, and performs directional control.

Initial selection is performed when driving is started. After starting excavation, a recalculation is performed from the data acquired with the survey system, etc., for each preset driving distance. When the calculation result indicates the need for changing control, a new jack pattern is selected from the knowledge base, and the jack pattern is changed. The distance set for judging jack pattern change can be optionally varied. Fig. 7 shows the control flow of this system.

The operating part of this system is described in IF/Prolog, however, C-language is used to link data of the survey system, control output part, data collection system, etc. The display of the EWS of this system is shown in Photo 1.

4. Results of Application

This system has so far been applied for practical work at two shield working sites for direction control. The results are described in the following:

4.1 Outline of the Work

An outline of the work is shown in Table 1:

Table-1 Outline of Work

	Yao Shield	Itsukaichi Shield
Purpose	Public Sewerage	Storm sewage
Total Length Driven	572.37 m	492.70 m
Working Method	Mud shield method	Mud shield method
Geological Conditions	Silt mixed with sand	Sand mixed with silt
External Diameter of Shield Machine	¢ 2880 mm	¢ 3480 mm
Shield Jack	80 ton x 10	80 ton x 14
External Diameter of Segment	¢ 2750 mm	¢ 3350 mm
Length of automatic Driving	45 m	170 m

4.2 Results of Automatically Controlled Driving

An example of the driving locus of the automatic control range in the Itsukaichi shield is shown in Fig. 8. Moreover, the frequency distribution of the driving locus of the shield machine in the manual control range due to the judgement of an operator and in the automatic control range due to this system are shown in Fig. 9. The driving locus in the automatic control range is as good as the locus of the manual control range of an operator, and the locus is within the control limit value. The location of finally assembled segment is also finished without any problems in comparison with the manual operation range.

5. Conclusion

The results of research and development performed up to this time verified that the control method of this control system is very effective as a means of controlling relatively subjective and ambiguous factors. It is expected that the knowledge base will be replenished by accumulating working data with the repeated application of the system to actual work, and the system will be improved to be comparable to skilled operators under any working conditions.

On the other hand, it is also planned to make shield work more automatic and highly precise by constructing an expert system with driving controls other than directional control.

Acknowledgment

We express our sincere thanks to the concerned who offered assistance in the development of this direction control system.

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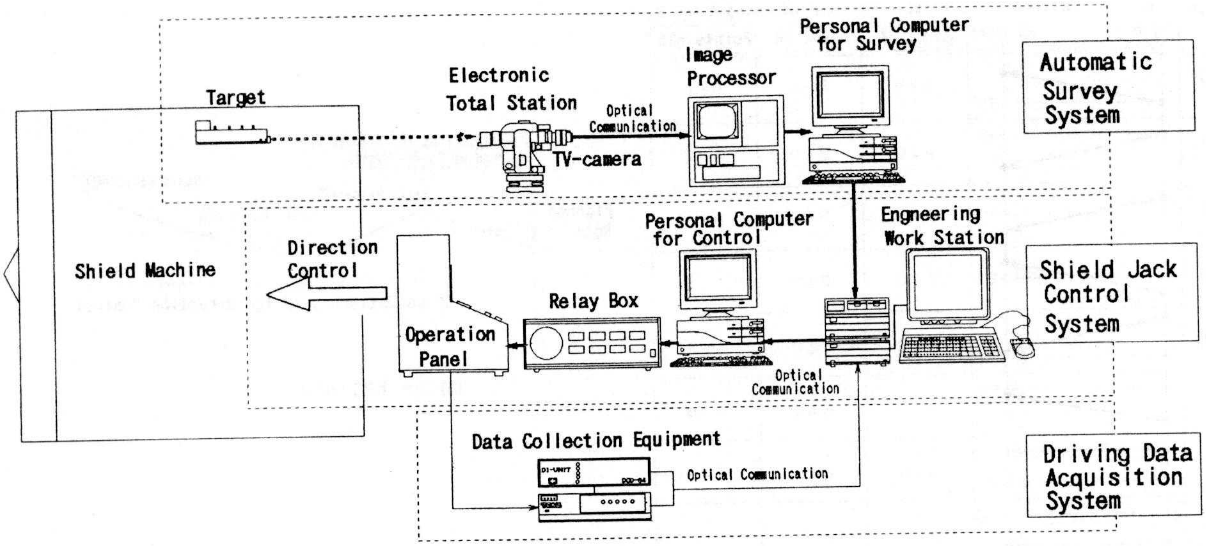


Fig. 1 Constitution of the Direction Control System

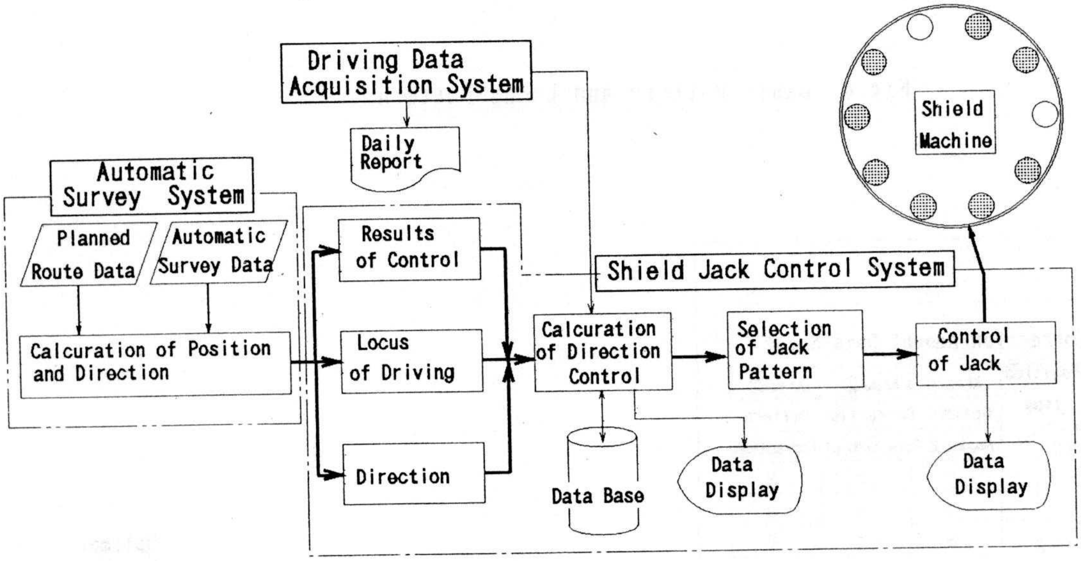


Fig. 2 Outline of Control System

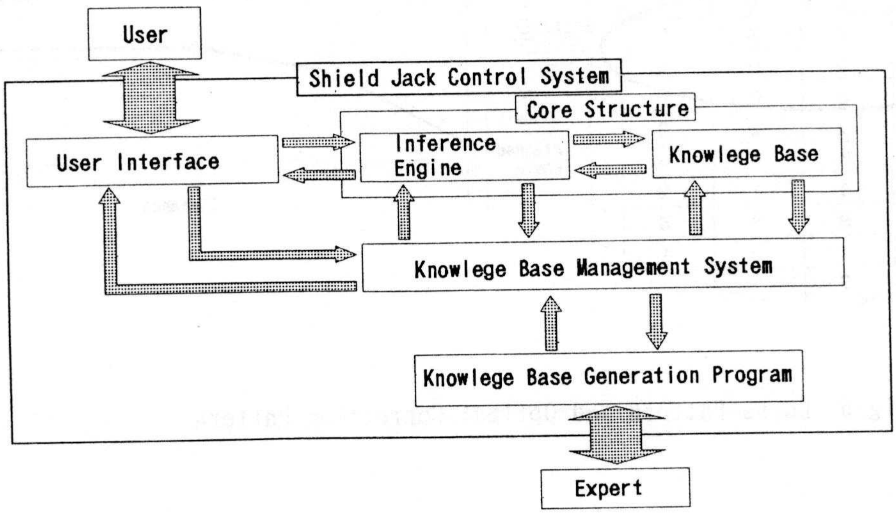
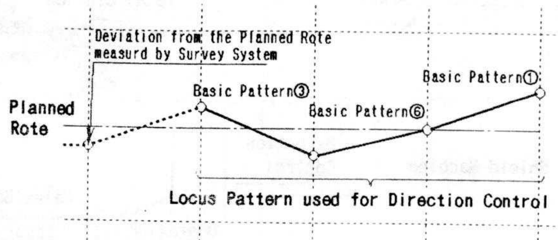


Fig. 3 Basic Structure of Shield Jack Control System software

Pattern No.	Form of Pattern (A) Point (B) Point	Relative Position of Point A And B: Point A	Point B	Points A&B
①		A≧0	B>0	A<B
②		A≦0	B<0	A>B
③		A>0	B<0	A>B
④		A<0	B>0	A<B
⑤		A>0	B≧0	A>B
⑥		A<0	B≦0	A<B
⑦		A≧0	B≧0	A=B
⑧		A<0	B<0	A=B

Basic Pattern



Locus Pattern

Fig. 4 Basic Pattern and Locus Pattern

Correction Amount Data Sheet

Locus Pattern \ Item \ Position	Area①	Area②	Area③
	Optimal Correction Pattern		
	Amount & Direction of Correction		
1-1-1	7	7	5
	-1	-2	-3
1-1-3	8	6	6
	1	1	2
1-1-5	7	7	5
	1	0	-1
1-1-7	7	7	7
	0	0	0
1-3-2	8	6	6
	1	2	2
1-3-4	7	5	5
	-1	-1	-2
1-3-6	8	8	6
	-1	0	1
	7	7	

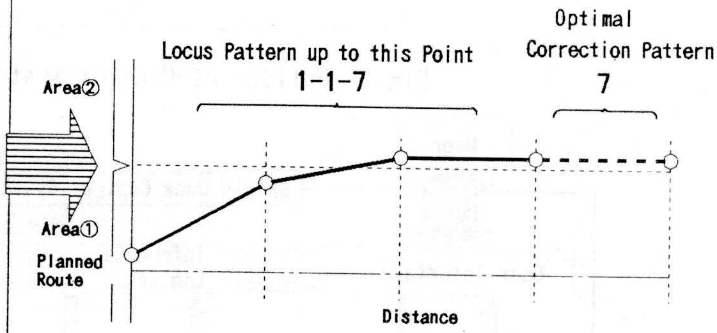


Fig. 5 Locus Pattern and Optimal Correction Pattern

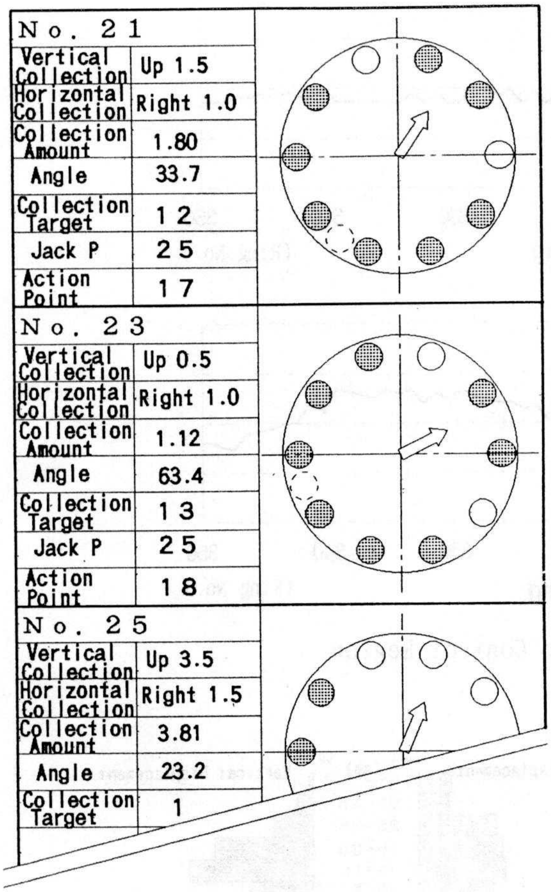


Fig. 6 Knowledge Base for Jack Pattern

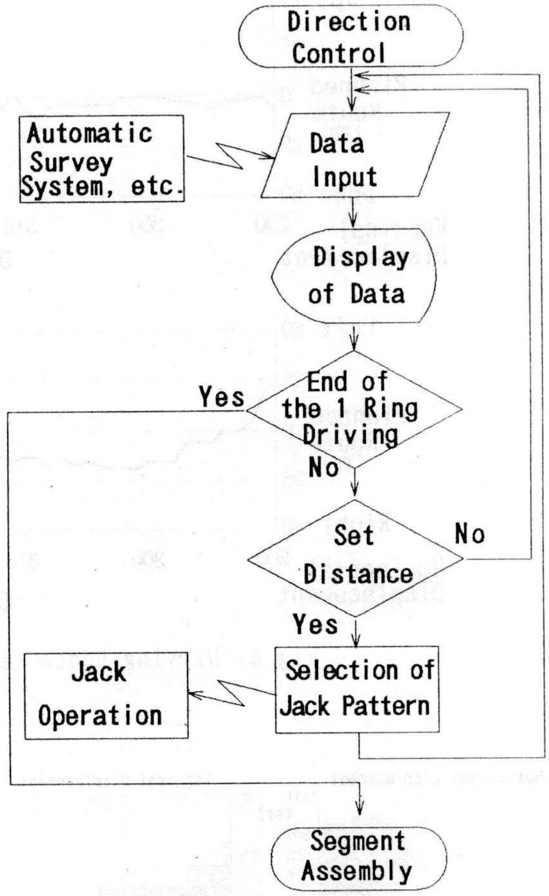


Fig. 7 Flow of System Control

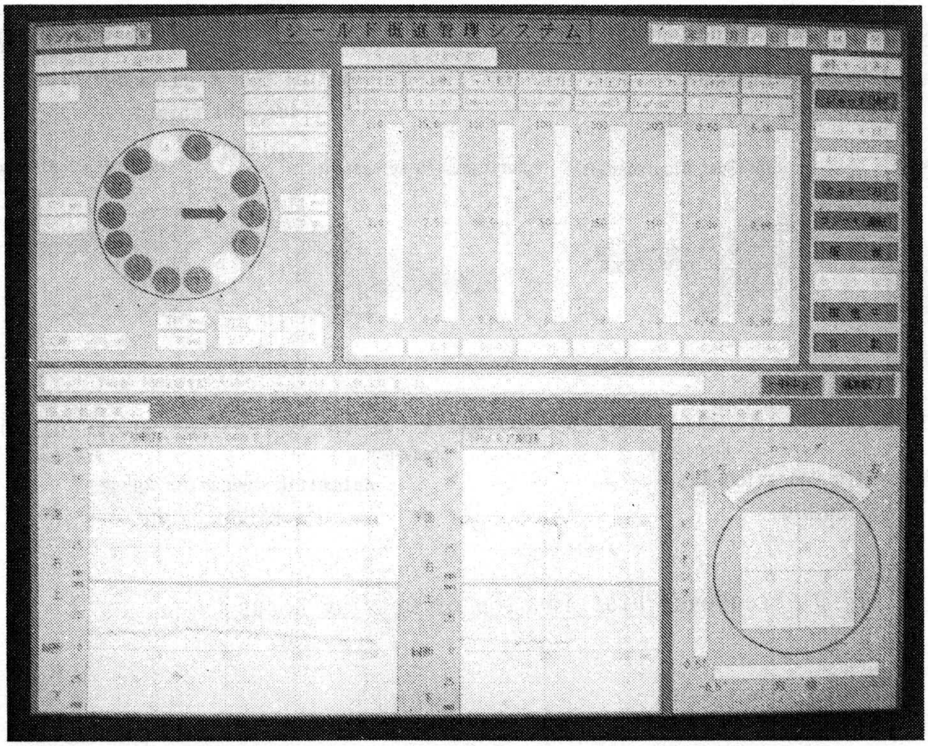


Photo 1 Display of EWS

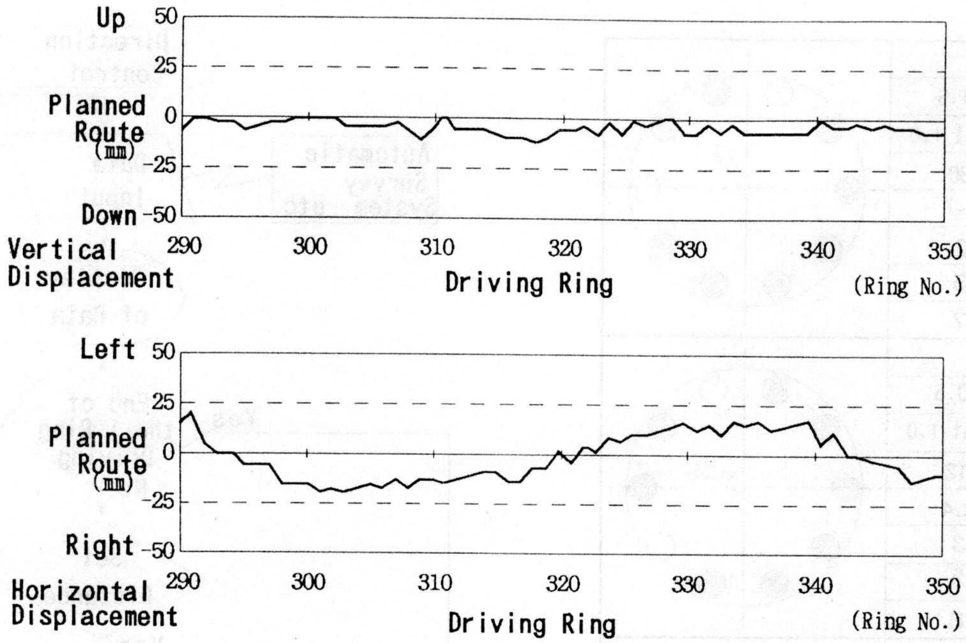


Fig. 8 Driving Locus of Automatic Control Region

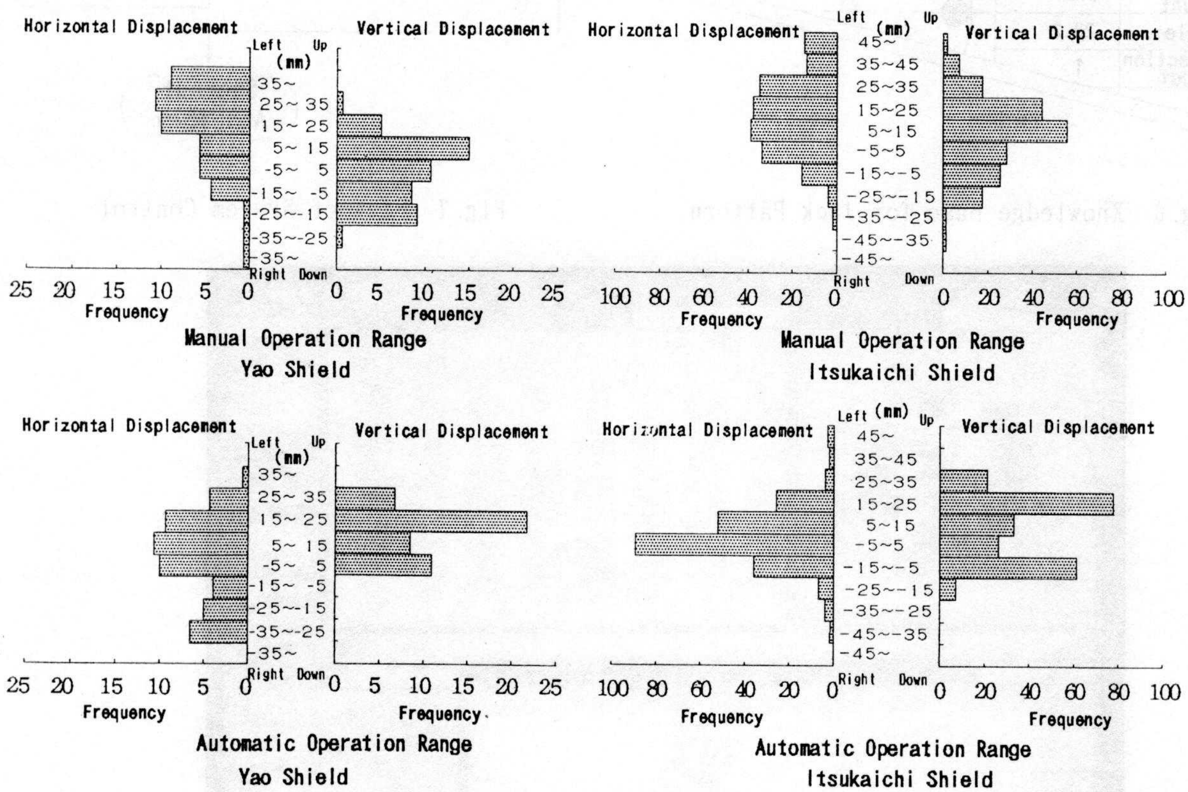


Fig. 9 Frequency Distribution of Driving Locus